

THE NBS THREE-STATION TECHNIQUE FOR S-66 FARADAY ROTATION STUDIES

by

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The history of ionospheric studies using satellite signals at NBS began shortly after the launching of the first Sputnik. After a period of experimentation as to the best method, we settled upon the observation of Faraday rotation of the plane of polarization as the most productive of ionospheric information with reasonably simple equipment.

The early Sputnik observations were made at their frequency of twenty megacycles per second. At this frequency, the plane of polarization rotates on the average once every four to six seconds. A data point is obtained each time the signal goes into a null as received on a fixed linearly polarized antenna; at these instants we know the polarization is orthogonal to our receiving antenna, and so we observed, typically, a null every two or three seconds. This data rate provided a resolution of ionospheric irregularities of about 25 kilometers.

The closely-spaced frequencies of 40 and 41 megacycles per second transmitted from the ionospheric beacon on S-66 permit the resolution of the ambiguity as to the total number of rotations of the plane of polarization. However, since the Faraday rotation rate is inversely proportional to the square of the frequency, the number of data points obtained using fixed antennas as the satellite crosses the sky is decreased by a factor of four; typically, nulls are observed every ten or twelve seconds, and the size of the smallest irregularities which can be observed increases to about 100 kilometers.

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Other experiments at NBS involving satellite signals employed three spaced stations deployed parallel to the subsatellite path, with Faraday rotation observations made at all stations. Here it was proved possible to triangulate on the irregularities and essentially map the electron distribution in the plane scanned out by the lines of sight from the satellite to the three stations.

When the characteristics of the ionospheric beacon for S-66 were settled upon, we proceeded to design an experiment to utilize the spaced station technique, the two closely spaced frequencies of 40 and 41 megacycles per second, and to increase the data rate by scanning the polarization of the receiving antenna, and in addition to improve the type of data recording so that scaling procedures would be speeded and simplified. It is this system which will be described here.

Briefly, then, our S-66 experiment consists of the following parts. First, the receiving antennas are scanned in polarization at a rate of approximately  $180^\circ$  per second, so that one data point (null) is observed for each  $180^\circ$  of scan. Second, the data is telemetered from the remote stations to the central station for display and recording. The problem of time comparison between records made at different locations is eliminated by this technique, since all station data is recorded together at the central station. Third, a display and recording technique is used that produces records which are quick and easy to scale. These records are compared with those made using fixed antennas and strip-chart recorders later. The recording technique involves the simultaneous display of the data for three stations, two frequencies for each station, on side-by-side oscilloscope tubes, and photographing them all together, with time marks and identification as required.

The first slide is a schematic representation of the experiment, with the central station near Boulder, and the other stations deployed approximately 75 kilometers northeast and southwest parallel to the subsatellite path for passes from south to north. Here we see the telephone lines which are used to transmit commands to the remote stations and receive data from them. The lines can also be used for voice communications during the brief and infrequent times when the stations are visited for checking and maintenance. The south station is located on National Forest land in the mountains near Bailey, Colorado, and the north station is on the land occupied by the NBS stations WWVB and WWVL near Fort Collins, Colorado.

The second slide shows a block diagram of the field equipment. The antenna consists of a pair of crossed dipoles so mounted as to provide essentially all-sky coverage. The polarization scanning is accomplished electronically, and the details will be shown later. The scanning technique presents to the receivers on 40 and 41 Mc/s signals similar to those which they would receive from a single dipole rotating at the scanning rate. The receivers are solid-state, total power receivers with bandwidth sufficient to accommodate the doppler shift. The AGC from the receivers is FM telemetered to standard IRIG channels over the phone line back to the central station. The lowest IRIG channel is used in the other direction to transmit commands to the remote equipment using resonant reed relays. One tone is required for the equipment to operate at all, so that in the event of a phone line outage the equipment reverts to the minimum power consumption mode. Other modes of operation can be commanded: the antenna scanning can be stopped in a reference position;

calibration signals can be transmitted from a test loop to check the system performance completely, including antennas, on both frequencies; the VCO's can be switched to transmit battery voltage data, and a heater in the electronics box can be turned on in very cold weather. In addition, as mentioned, it is possible to talk over the line when the station is visited for service.

The next slide shows the details of the polarization scanner. Here, the signals from orthogonal dipoles are combined in a hybrid to produce two outputs corresponding to the two circularly polarized components of the received signal. These remain constant in amplitude but the phase between them changes as the plane of polarization rotates. The phase between them is determined by recombining the circular components in a second hybrid, with the phase of the signal entering one side of this hybrid being shifted stepwise in 18 steps over a range of  $360^\circ$ . Thus, at the phase shifter step for which the two hybrid input signals are out of phase, a null is produced at the receiver input. The hybrids and phase shifter are sufficiently broad band so that the system functions adequately at both 40 and 41 Mc/s. The phase shifter consists of 18 phasing lines which are consecutively switched into the line with a pair of 18-position diode RF switches which are driven by a ring counter. Additional steps on the ring counter are used to provide synchronization for the display, and for the substitution of a reference resistor and a fixed-amplitude calibrating signal during each scan.

The next slide shows a photo of the scanning switch, with the diodes inside the eighteen phasing lines connected between them.

The next slide shows one of the complete field installations, with the low antenna and bent dipoles for all-sky coverage, and the three picnic coolers. One of these houses the RF switch, the second the receivers, ring counter, and telemetry electronics, and the third contains two large storage batteries. At the remote sites, the three boxes have been buried in the ground to provide some protection from the environment. The set-up shown is at the central station, and has been run without being buried to provide a more severe environment for checking equipment performance than that experienced at the remote stations. The remote stations are also equipped with thermoelectric converts, fired by bottled gas, to keep the batteries charged. This is important during the winter when it has proved necessary to operate the 40-watt heater in the electronics box quite a lot during cold spells. Since the mountain location is relatively inaccessible during the winter, this has proved more satisfactory than the periodic substitution of charged batteries. A 100 pound gas bottle has run the station for about ten weeks, with a reserve battery capacity sufficient for several additional weeks until weather and snow conditions permit replacement.

The next slide shows the block diagram of the central station equipment. Here, the telemetry signals from the three stations are combined and all six data channels recorded on a single magnetic tape channel using an Ampex audio tape recorder. Time signals occupy the other tape channel. The telemetry channels are then separated with channel filters and distributed to discriminators. Sync information is extracted for each station, and a sweep generated for a pair of oscilloscopes displaying the data from that station. The six channels from the three

stations are deployed side by side and produce vertical deflection on the scopes. The composite display is photographed using a continuous film motion camera. Note that it is not necessary for the polarization scanning at the various stations to be synchronized for the system to function. By using vertical deflection, exposures are not critical, and amplitude information is not lost, if it should be desired to look for scintillations. Films can be produced from the tapes whenever this is required.

The next slide is a photograph of this installation, showing the command and recording equipment in the racks to the left; the set of monitor scopes on top of the desk, and the array of scope tube facing the camera to the right. Rather than attempt building a light-tight hood to enclose the camera and display tubes, we chose to close off the entire corner of the room with black plastic sheeting, so that the entire operation is carried out in the dark. A maze-type entrance is provided so that it is possible to enter the room without interrupting the recording. Note the darkroom safelights, which provide sufficient general illumination. A blue filter on the camera prevents film fogging with the yellow safelights and red pilot lights throughout the equipment. The black plastic walls can also be raised up if it is necessary to move large equipment in and out, or for taking pictures such as this one.

Now, let us look at the data. First, a slide showing a strip-chart recording made with a fixed antenna. The very irregular spacing of nulls on the two records indicates the presence of an ionospheric irregularity. However, it is defined by only a few nulls, and it is not possible to determine whether the rotation of the plane of polarization reversed in its direction on either or both frequencies.

In the next slide, the same data is displayed, together with the photographed display made with the equipment described. Note that each scan across the film corresponds to  $180^\circ$  of rotation of the equivalent dipole. Here, the orientation of the plane of polarization can be identified on each scan, and the position easily followed in detail throughout the irregularity. Note that the direction of rotation did indeed reverse, which could not be unambiguously determined from the strip-chart recording.

The final slide shows the complete three-station record for this same period, and an additional less disturbed period following it. The time delay between appearance of the same features of this irregularity at the spaced stations is immediately obvious. It is this time difference which makes it possible to triangulate on the irregularities, and produce for each pass of interest a map of the plane containing the satellite path and the three observing stations, showing the distribution of the electrons in this plane and hence detailing the ionospheric irregularities in a way not previously possible.